14.2 Latent heat

Preliminary work: Observing the changes that take place when water is heated until it boils
Experiment: Measuring the specific latent heat (of vaporisation) of water
Full investigation: Measuring the specific latent heat (of vaporisation) of water more accurately

Preliminary work: Observing the changes that take place when water is heated until it boils

Apparatus

- beaker of water
- Bunsen burner, tripod, gauze, bench mat
- electronic or mercury thermometer (0–110 °C)
- safety glasses

Plan

- Fill the beaker two-thirds full of cold tap water, light the Bunsen beneath it and record all that you see, including the changing temperature, until the water is boiling freely.

Analysis

Put your observations into a table like this:

Observation	Temperature
Mist appears on the outside of the beaker.	
Small bubbles rise from the bottom of the beaker to the top.	
'Wisps' appear above the water surface.	
Large bubbles appear and disappear on the bottom of the beaker.	
Large bubbles get to the surface where they burst and whip the surface into a turmoil.	
The water boils steadily but gets no hotter.	

Experiment: Measuring the specific latent heat (of vaporisation) of water

Apparatus

- old plastic electric kettle
- measuring cylinder (100 cm^3)
- thermometer
- stop clock or watch
- safety glasses and oven gloves

Plan

Extreme care is needed during this experiment. Wear safety glasses, and remember that water vapour is invisible and contains a lot more internal energy than boiling water. Arrange the apparatus so that you can operate it from a distance and there is no danger of you, or others, being scalded by the steam or boiling water.

- Carefully measure out 1 kg (=1 litre) of water into the kettle and measure its temperature (θ).

- Leave the lid off the kettle, switch on and start the stop clock. Note the time (t) it takes the water to boil.
- Keep the clock running and let the water boil for 5 minutes. (You may have to over-ride the automatic switch on the kettle.)
- Carefully pour the water that remains into the measuring cylinder, to find out the mass of water that has been boiled away.

Analysis

1 Use the time it takes the water to boil and the specific heat capacity of water to estimate the power supplied to the water by the heating element.

Specific heat capacity of water = 4180 J kg^{-1} K^{-1}
Energy supplied to the water = $1 \times 4180 \times (100 - \theta)$ J
Average power (P) supplied to the water = $4180\,(100 - \theta)/t$ W

2 Record all your readings and calculations as follows:

Mass of water = 1 kg
Time to reach boiling point (t) =
Temperature of water at start (θ) =
Rate at which energy is supplied to water by heater (P) =
Mass of water turned into vapour (m) =
Boiling time = 600 s
Energy supplied to water during boiling ($600 \times P$) =
Energy needed per kg to turn water into vapour at its boiling point ($600P/m$) =

Sample readings

Mass of water = 1 kg
Starting temperature = 24.0 °C
Time to reach boiling point = 3 minutes 23 s
Boiling time = 5 minutes
Mass of water boiled away = 230 g

Calculate the specific latent heat of vaporisation from these sample readings.

Answer

2.1 MJ kg^{-1}.

Evaluation

The method of calculating the average power supplied to the water (from specific heat capacity and temperature rise) is more precise than using the given power of the heating element. However, the energy supplied will not be an accurate figure, because some is used to heat the element and the body of the kettle. A second source of inaccuracy is the heat lost from the hot kettle by convection and radiation. Energy has to be supplied to make up for this, and less vapour is produced than if there had been no losses. Also, some of the vapour condenses and falls back into the water.

A 100 cm^3 measuring cylinder is suggested for measuring the water because, although it is laborious to use, it measures volume precisely. The quantity with the largest uncertainty is the mass of water that turns into vapour (m). It is obtained from subtracting two measurements, each uncertain by at least 4 g, and so has an uncertainty of 8 g in 200 g (= 4%). The uncertainty in

the calculated power supplied to the water comes from measurements of the initial mass of water (4 g or ~0.4%), the temperature rise (1 °C or ~2%) and the time to reach boiling (20 s or ~10%). These would give an overall uncertainty in the value of the specific latent heat of ~17%.

Full investigation

Measuring the specific latent heat (of vaporisation) of water more accurately

Apparatus As for the previous experiment, plus:

- digital balance
- electronic thermometer probe and datalogger

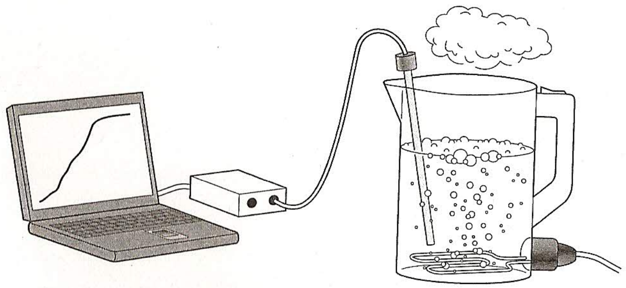

Figure 14.4

Plan Take the same safety precautions as in the previous experiment: see p. 174. Follow the same method, except:

- Use an electronic balance to measure the mass of water before and after boiling.
- Use an electronic thermometer and a datalogger to plot the temperature of the water as it is brought to the boil.
- Find the power supplied to the water near to the boiling point when losses will be similar to those during boiling.
- Boil the water for longer than 5 minutes to increase the quantity turned into vapour.

Analysis Power supplied to the water:

P = mass of water × specific heat capacity
× gradient of the temperature/time curve close to boiling point

Energy supplied to the water during boiling:

$E = P \times$ boiling time

Specific latent heat of water:

$L = E/$mass of steam produced

Use these equations to calculate the specific latent heat of vaporisation of water.

Sample readings

time after switch-on /s	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225
temperature /°C	73.8	76.6	78.8	81.0	83.0	86.0	90.0	93.4	96.0	97.8	99.4	100.4	101.0	101.4	101.6	101.8

The kettle was switched on at time 0 s and off at time 720 s.
The mass of water started at 1000 g and finished at 564 g.

Plot the temperature/time graph for the sample readings and estimate the gradient just before the water boils.
Calculate the power given to the water by the heater.

Answer ~2260 W.

Estimate the boiling time and the mass of vapour produced.
Calculate the specific latent heat of vaporisation of water.

Answer ~2.6 MJ kg^{-1} K^{-1}.

Evaluation Using a balance to measure the loss in mass of the water is more precise than pouring the water into a measuring cylinder. The uncertainty may be about 2 g in 400 g. However, water turns to vapour before it boils, and some steam re-condenses inside the kettle during boiling. This could involve an extra 2 g, giving a total uncertainty in the mass of vapour of 4 g (~1%).

Estimating the gradient of the temperature/time graph to calculate the power will introduce an uncertainty of ~5%.

The moment of boiling is not precise and introduces an uncertainty of ~20 s into the time of boiling. Lengthening the boiling time will reduce the significance of this to say 20 s in 500 s (~4%).

Overall, the uncertainty of the modified method will be ~10%. As with all experiments, there is a limit placed by the design on the accuracy that can be achieved.